Soft Gamma Repeater Burst Activity from Anomalous X-ray Pulsars

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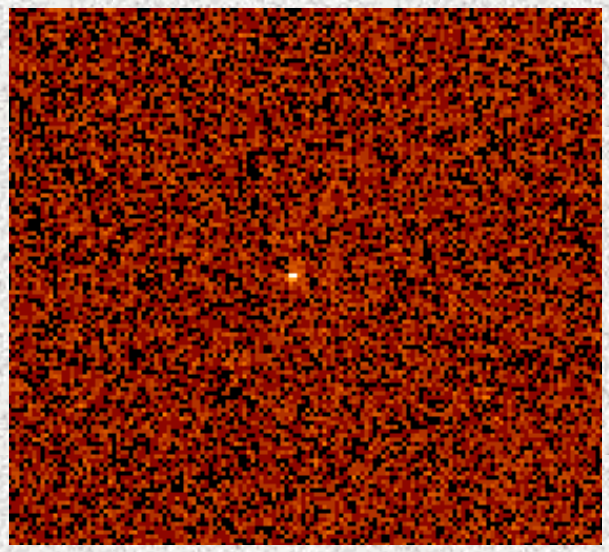
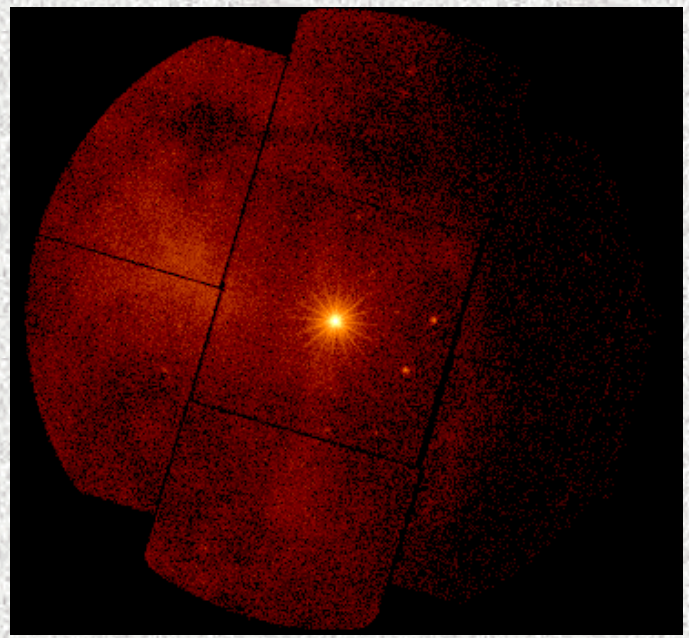
AXP Properties

- $L_x = 10^{35\text{-}36}$ ergs s^{-1}
- Two-component energy spectrum
  BB kT ~ 0.4-0.5 keV
  PL Γ ~ 2.5-4.0
- Spin periods ~ 6-11 s
- Spindown rates ~ 10^{-13} -10^{-11} s s^{-1}

1E 1048.1-5937



1E 2259+586



- 2/5 SNR assoc
- 3/5 IR counterparts
- Low Galactic scale height

Nature of the AXPs

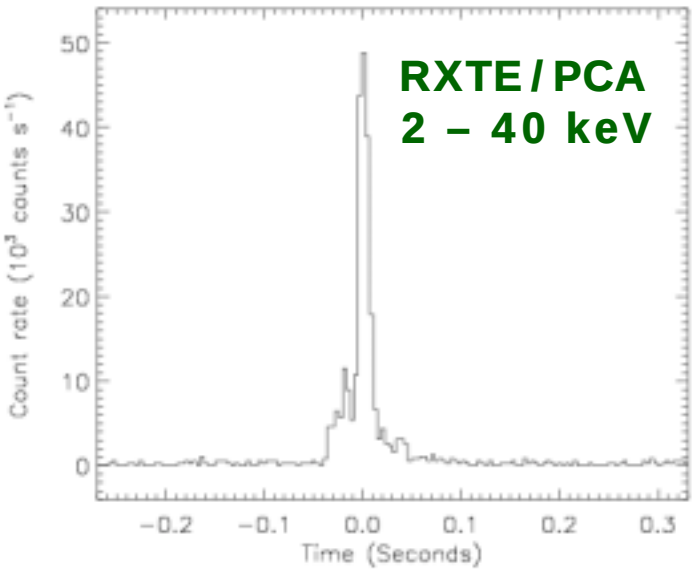
- Rotation powered neutron star – insufficient energetics
- Rotation powered white dwarf – SNR associations, age problem
- LMXB – inconsistent X-ray spectrum, no orbital Doppler shifts, age problem
- Fossil Disk accretion – inconsistent X-ray spectrum, IR counterparts too bright, high amplitude optical pulsations
- Quark star – still in its infancy, inconclusive
- Magnetar – consistent with most properties, still behind some of the observations

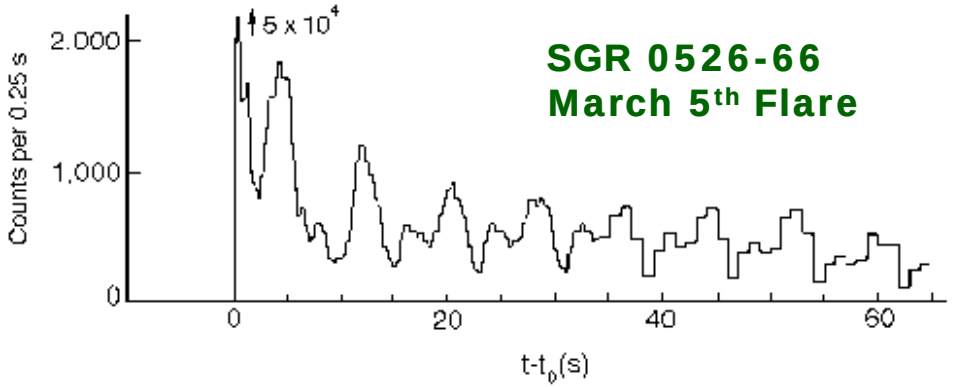
Magnetar Model

- Strongly magnetized neutron stars ($B_{dip} \sim 10^{14\text{-}15}$ G)
- Strong field consistent with rapid spindown
- Decay of the magnetic field powers the bright X-ray emission
- Model originally developed to explain super-Eddington bursts from SGRs

SGR Bursts and Flares

- Duration ~ 0.1 s
- Energy spectrum above 15 keV
  $dN/dE \propto E^{-1}\, e^{-E/kT}$
  kT ~ 20–30 keV
- $L \leq 10^{41}$ ergs s^{-1}





- $L \sim 10^{45}$ ergs s^{-1}
- Durations ~ minutes
- Clear pulsations in tail

Mazets et al. 1979

AXP $\stackrel{?}{=}$ SGR

AXP/SGR similarities as of mid-1990s:

- Similar persistent X-ray luminosities
- SNR associations?
- Periodicity in March 5th flare fit within AXP spin period range

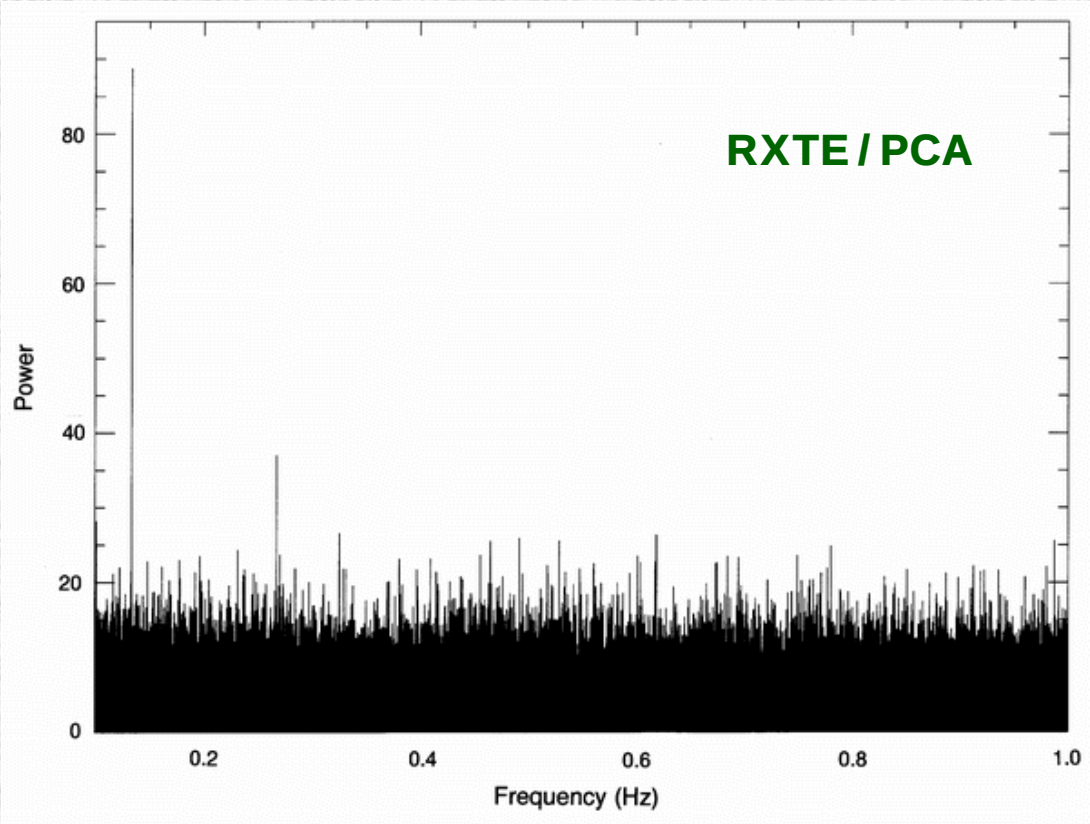
Thompson & Duncan 1996 predictions:

- SGR X-ray counterparts may show coherent pulsations
- AXPs may one day burst

SGR Pulsations

- Discovery of 7.5 s pulsations
- Rapid spindown
- Inferred field strength $B_{dip} \sim 10^{15}$ G
- Concluded SGRs were magnetars and SGRs were similar to AXPs

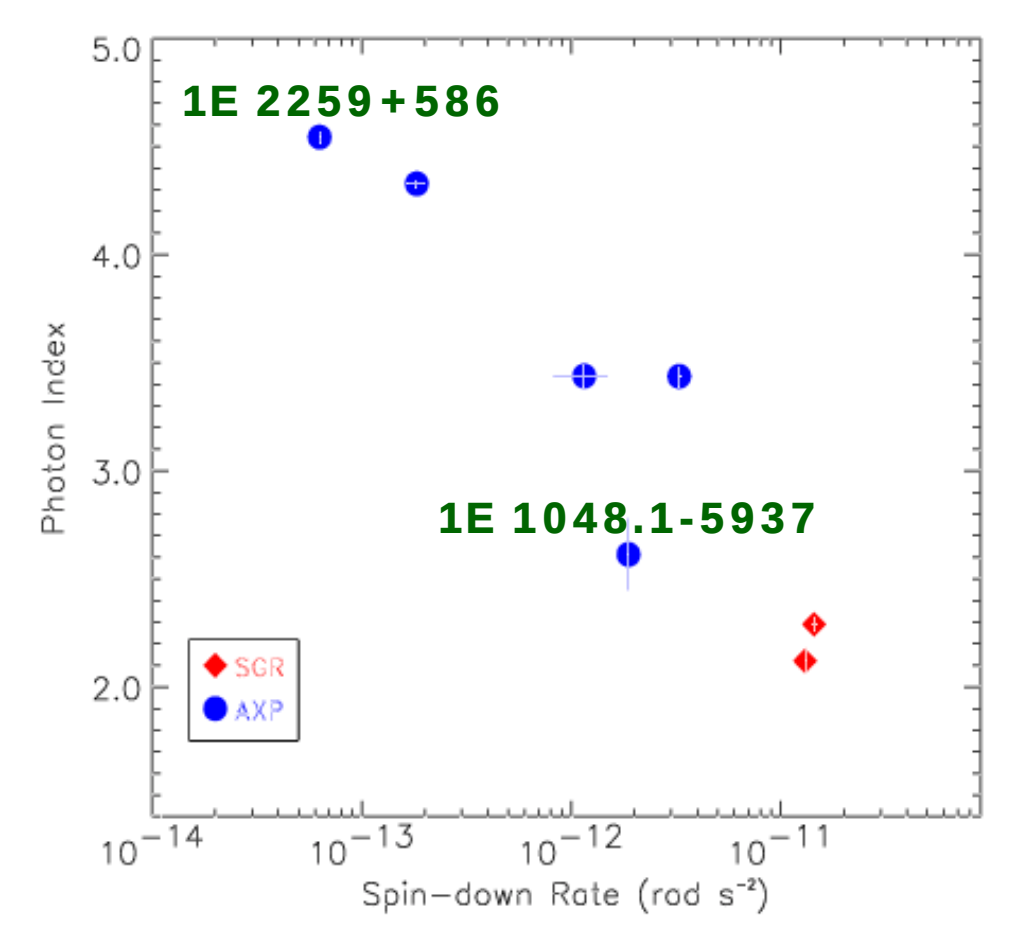
SGR 1806-20



Kouveliotou et al. 1998

Further Similarities

- Discovery of 5.2 s pulsations and rapid spindown in SGR 1900+14
  Hurley et al. 1999; Kouveliotou et al. 1999
- Two-component energy spectrum in SGR 1900+14
  Woods et al. 1999
- Continuum of spectral hardness



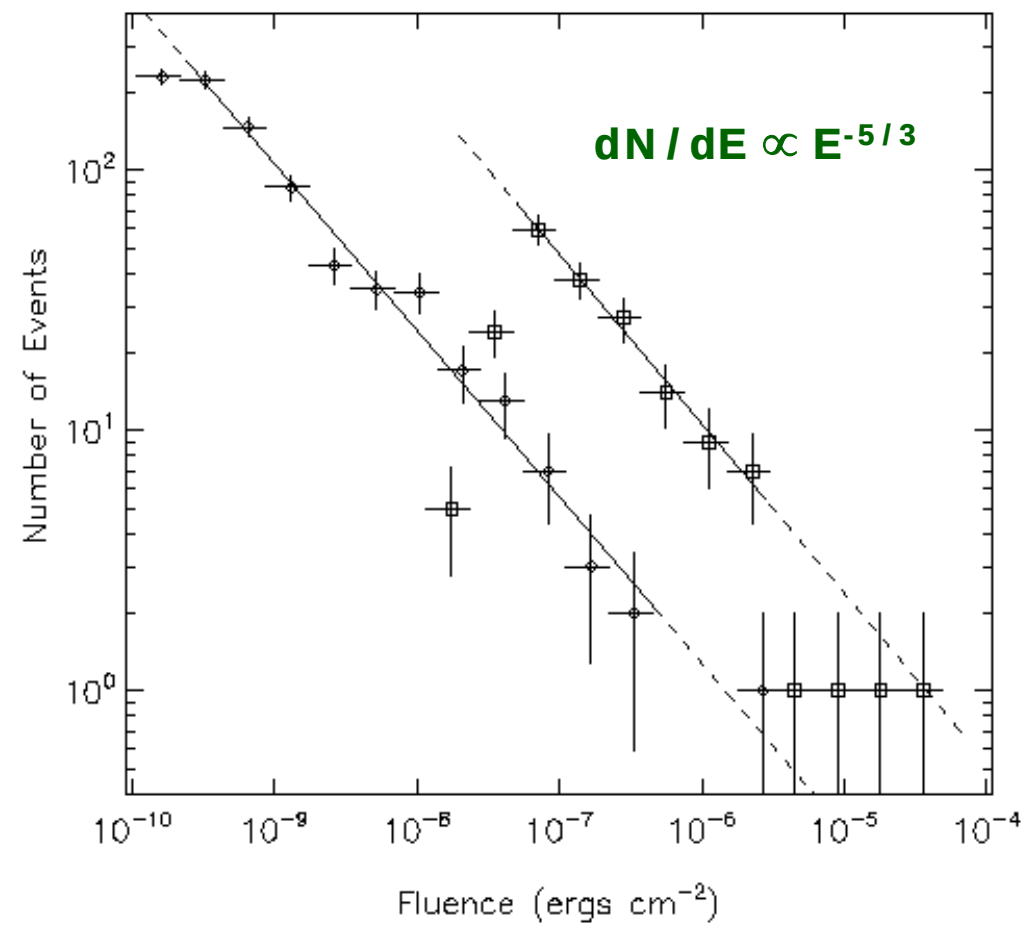
Marsden & White 2001

AXP Burst Search

- Nothing detected from AXPs in 20 years of observations with all-sky gamma-ray instruments
- Utilize 2.5 order of magnitude increase in detector sensitivity of the RXTE PCA to search for bursts from AXPs

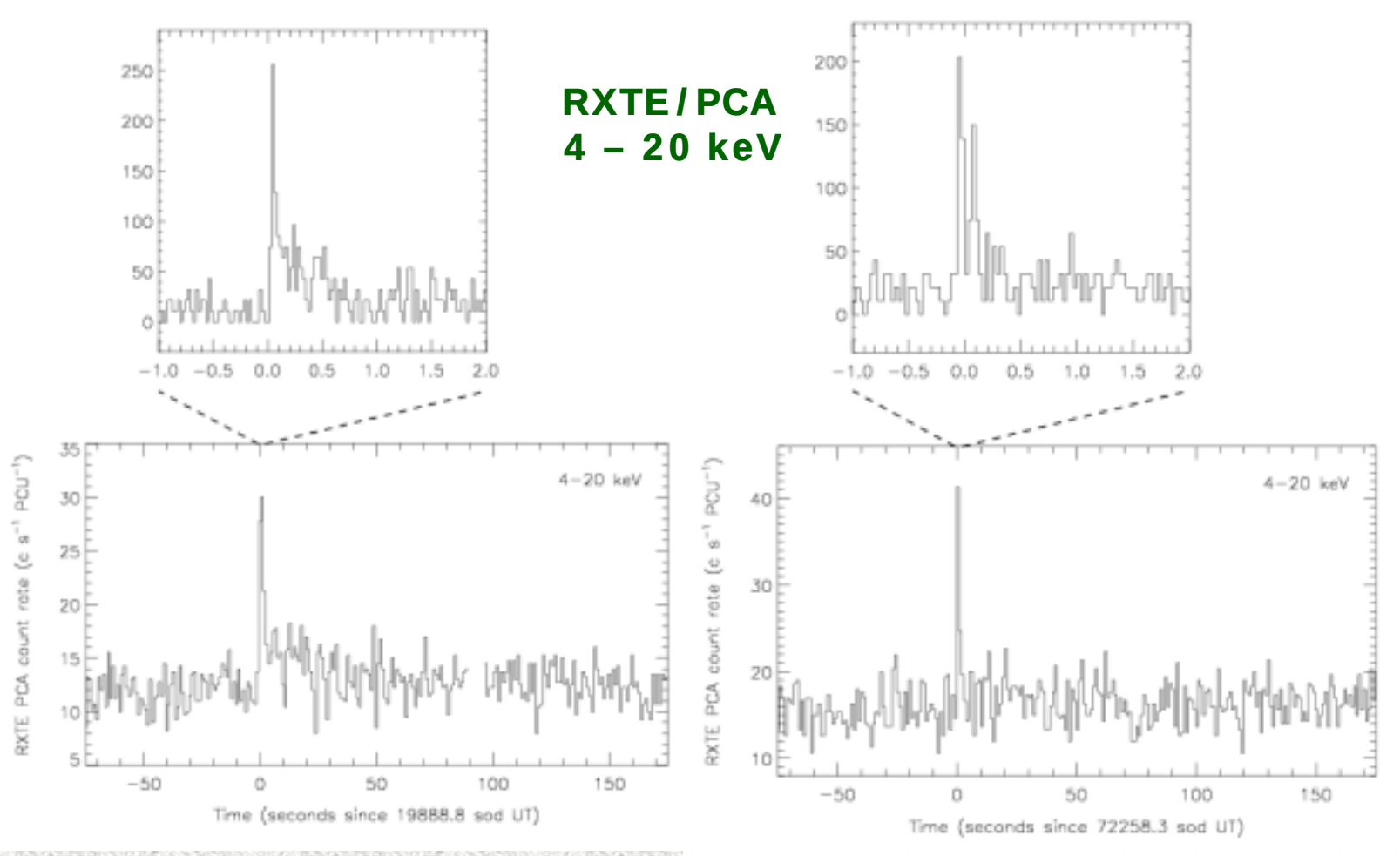
Gogus et al. 1999

SGR 1900+14



Bursts from 1E 1048.1-5937

Burst 1 **Burst 2**

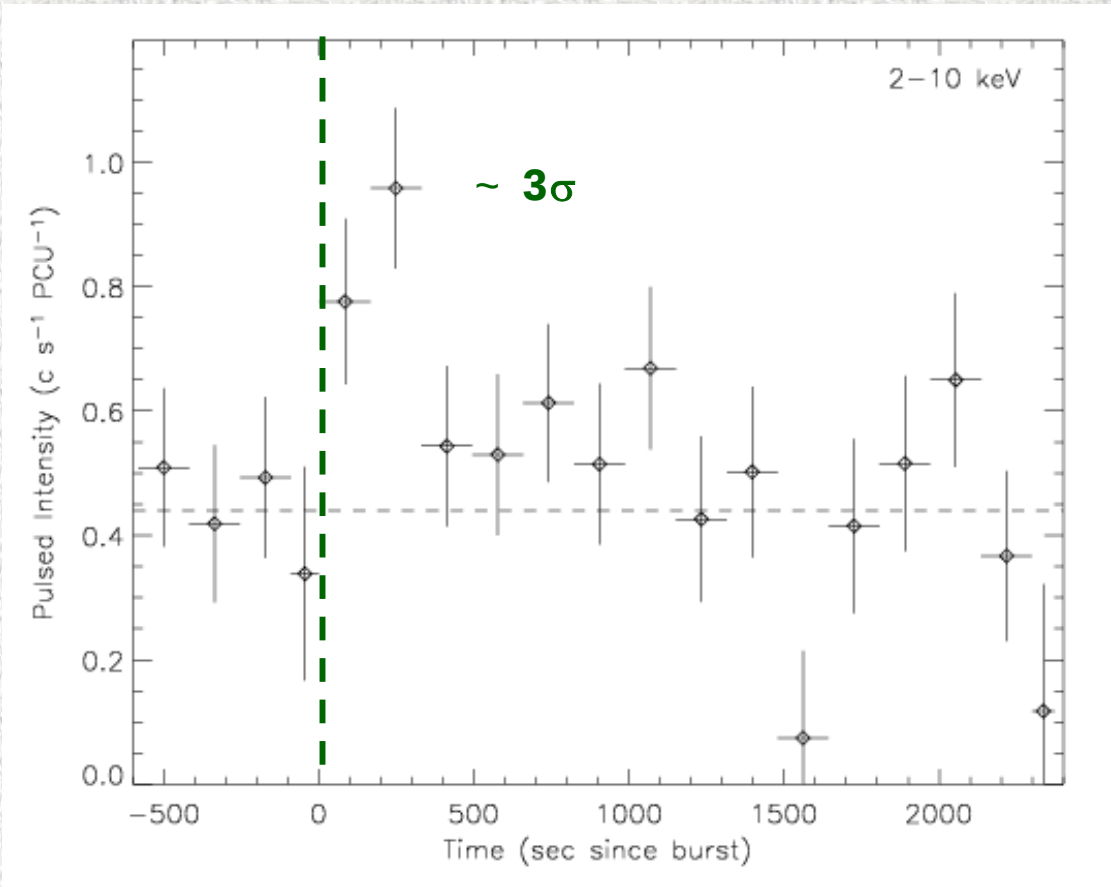


Gavriil, Kaspi & Woods 2002

Pulsed Flux Increase?

- Marginal increase in pulsed flux following burst 1
- Marginal increase in pulsed flux during epoch surrounding bursts relative to long-term behavior
- Not conclusive

1E 1048.1-5937 Burst 1

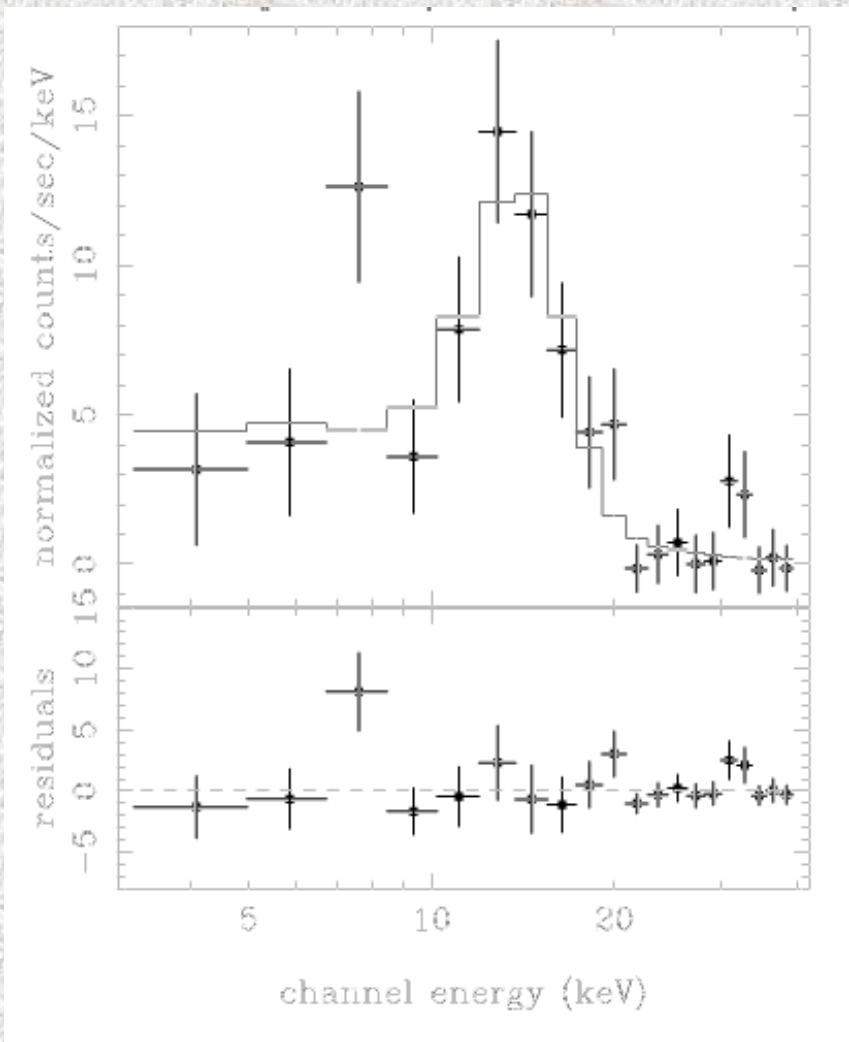


Gavriil, Kaspi & Woods 2002

Spectral Line

- Broad line or ridge near 14 keV
- Less significant features at 7 and 30 keV

1E 1048.1-5937 Burst 1



Gavriil, Kaspi & Woods 2002

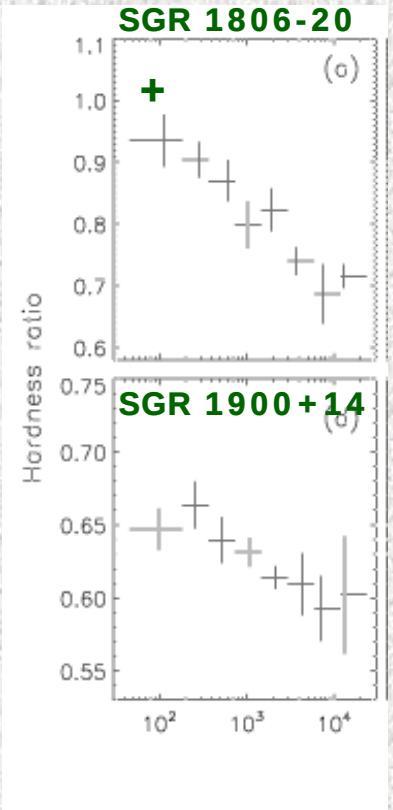
Burst Origin?

- Type I bursts? – wrong spectrum, fast rise times, no known bursters in fov, spectral line
- Type II bursts? – short rise times, rarity of such sources (2 known in Galaxy), spectral line
- GRBs? – low probability of two GRBs in small fov (9×10^{-5})

Likeness to SGR Bursts

Similar Properties

- Rise times
- Duration, time history, and spectrum of burst 2
- Clustering in time

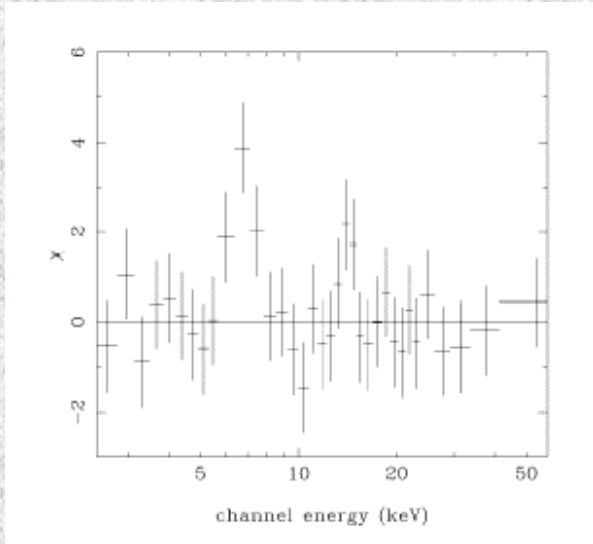


Gogus et al. 2000

Consistent Properties

- Long tail of burst 1
- Spectral feature

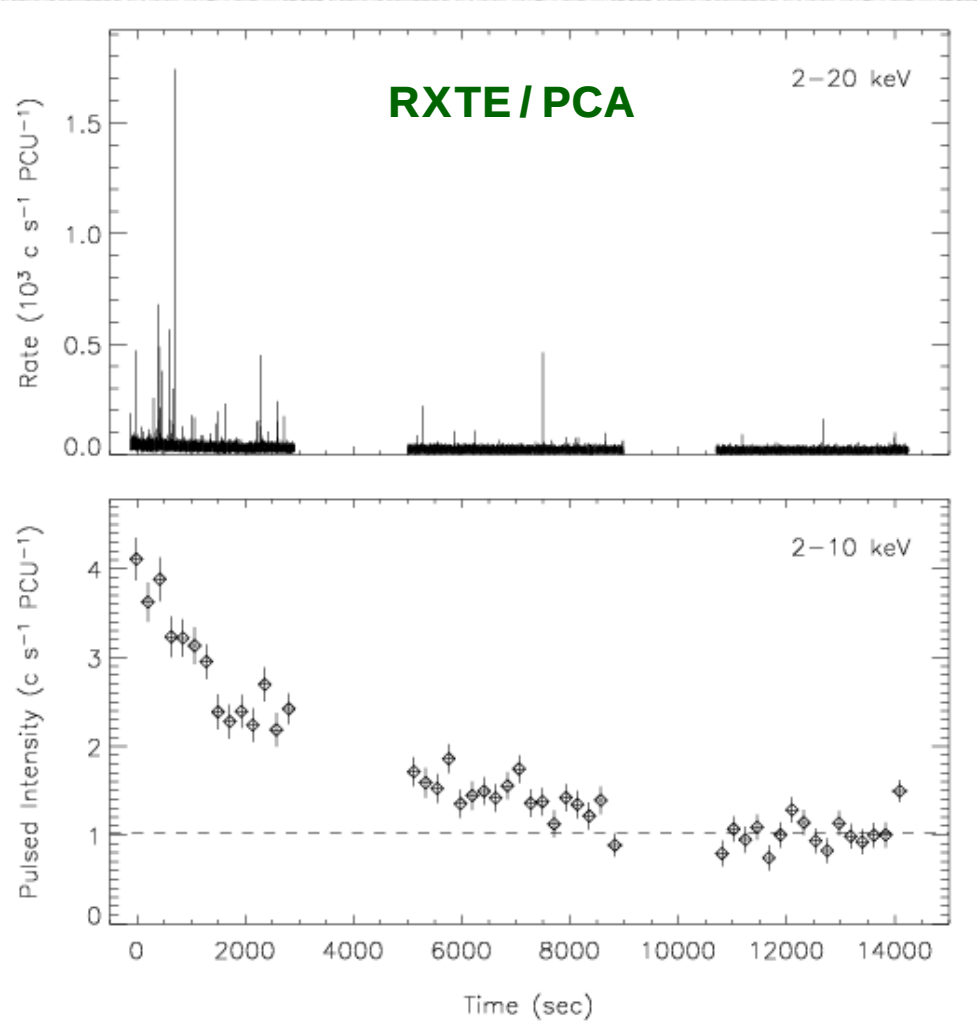
SGR 1900+14



Strohmayer & Ibrahim 1999

Bursts from 1E 2259+586

- More than 80 bursts detected within 11 ksec
- Correlated change in pulsed flux

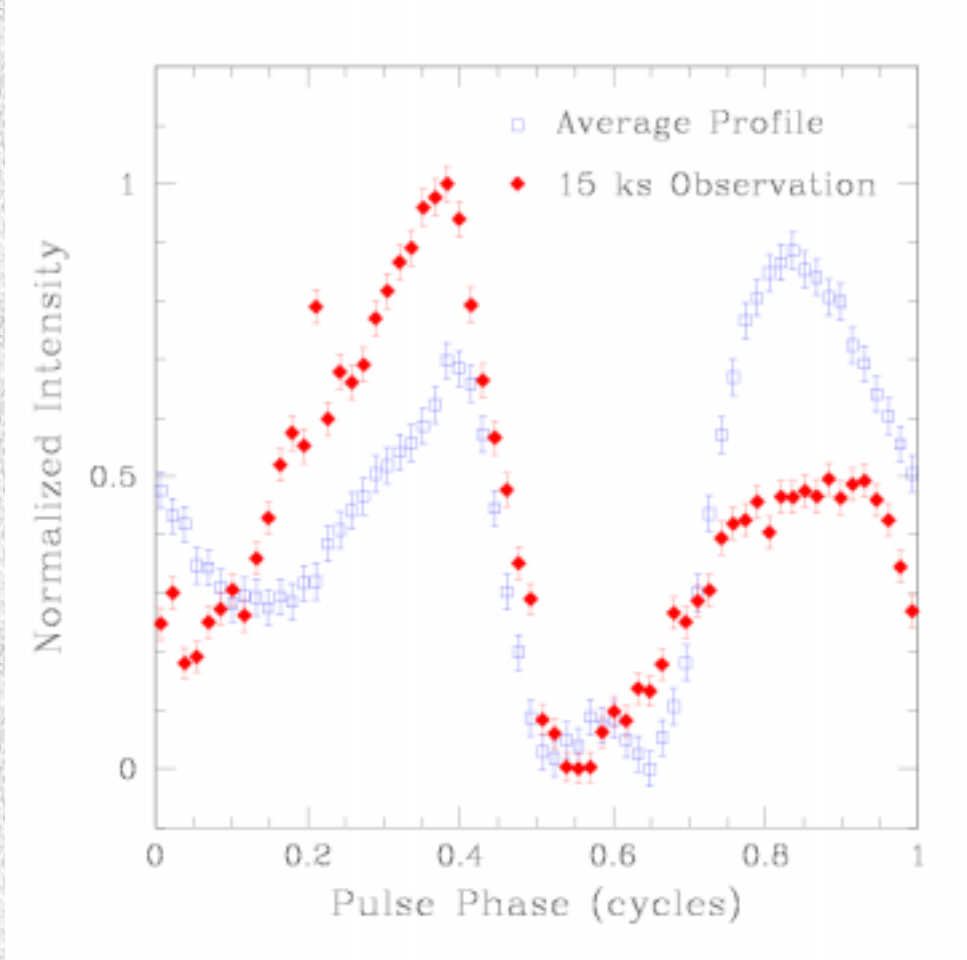


Kaspi et al. 2002

Pulse Profile Change

- Change in pulse profile coincident with burst activity
- No doubt that the AXP was the source of the bursts

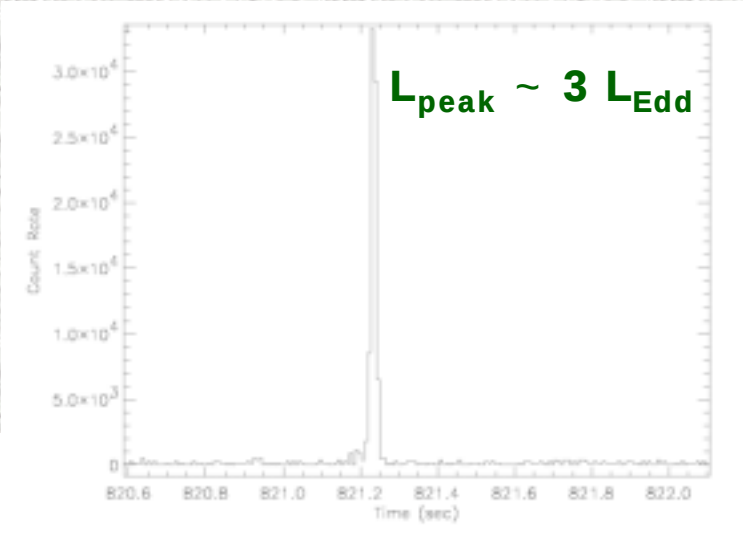
1E 2259+586

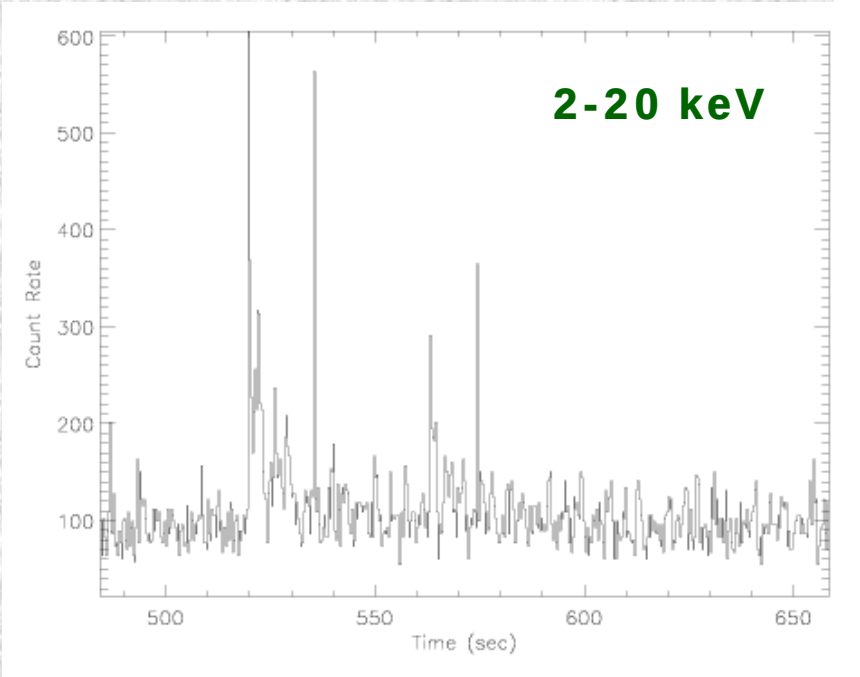


Kaspi et al. 2002

1E 2259+586 Burst Properties

- Most bursts are very "SGR-like" in their temporal and spectral properties



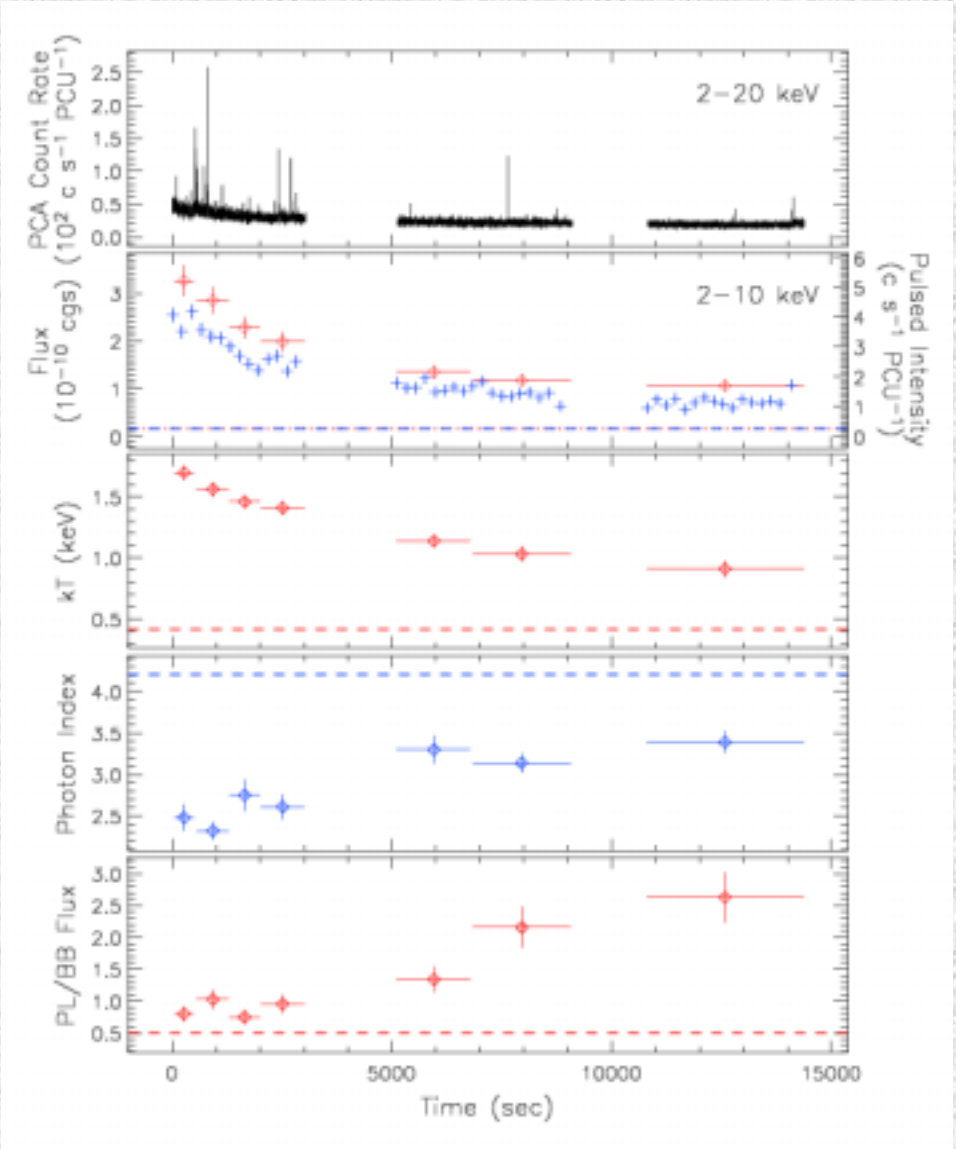


- A small fraction of events (≤10%) have extended tails, similar to the tail seen following burst 1 from 1E 1048.1-5937

Gavriil et al. 2003

1E 2259+586 Spectral Change

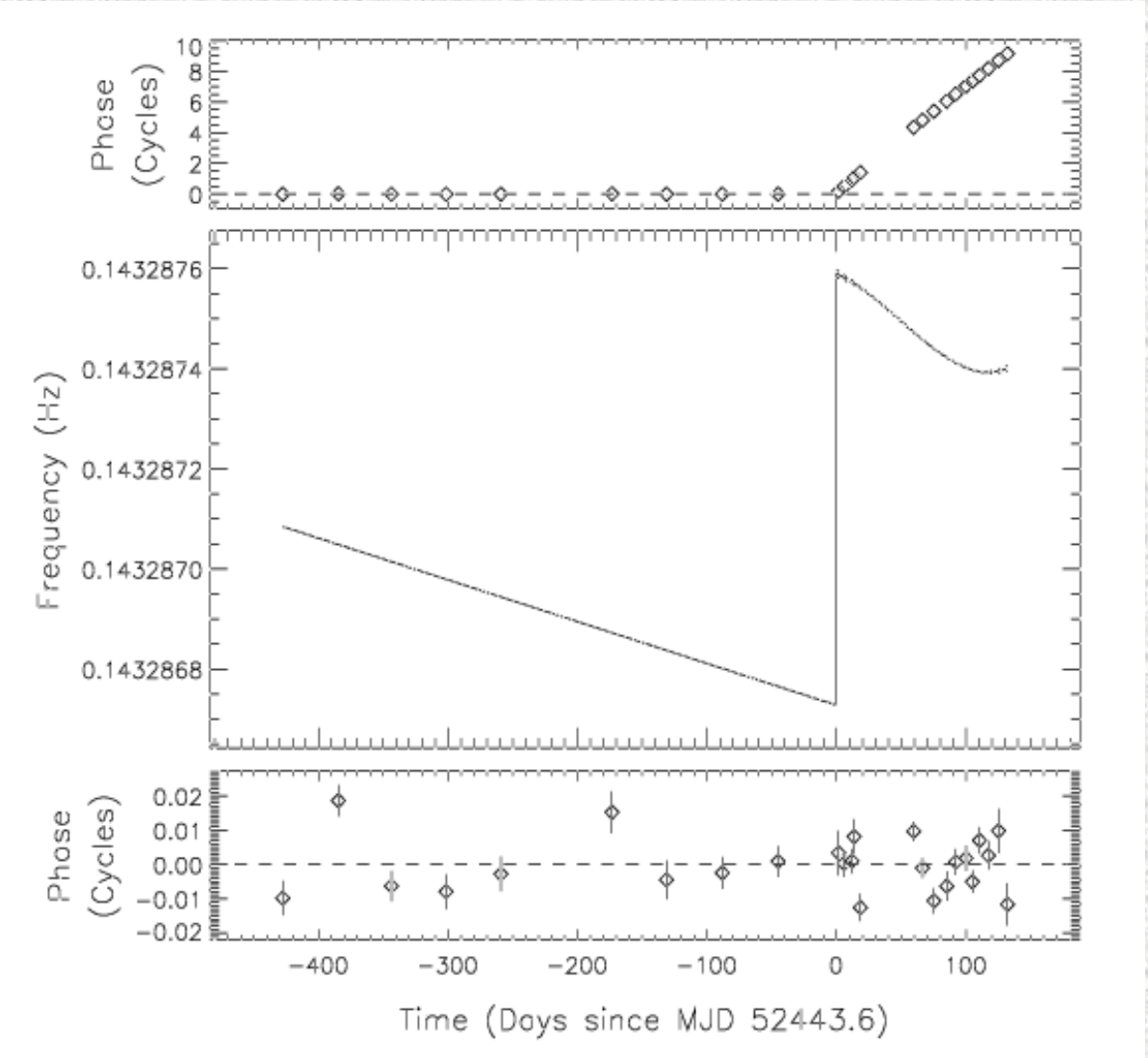
- Pulse fraction decreased
- No single component model fits the tail spectrum
- Spectrum hardened initially, then rapidly moved back toward quiescent values



Kaspi et al. 2003

A Glitch in 1E 2259+586

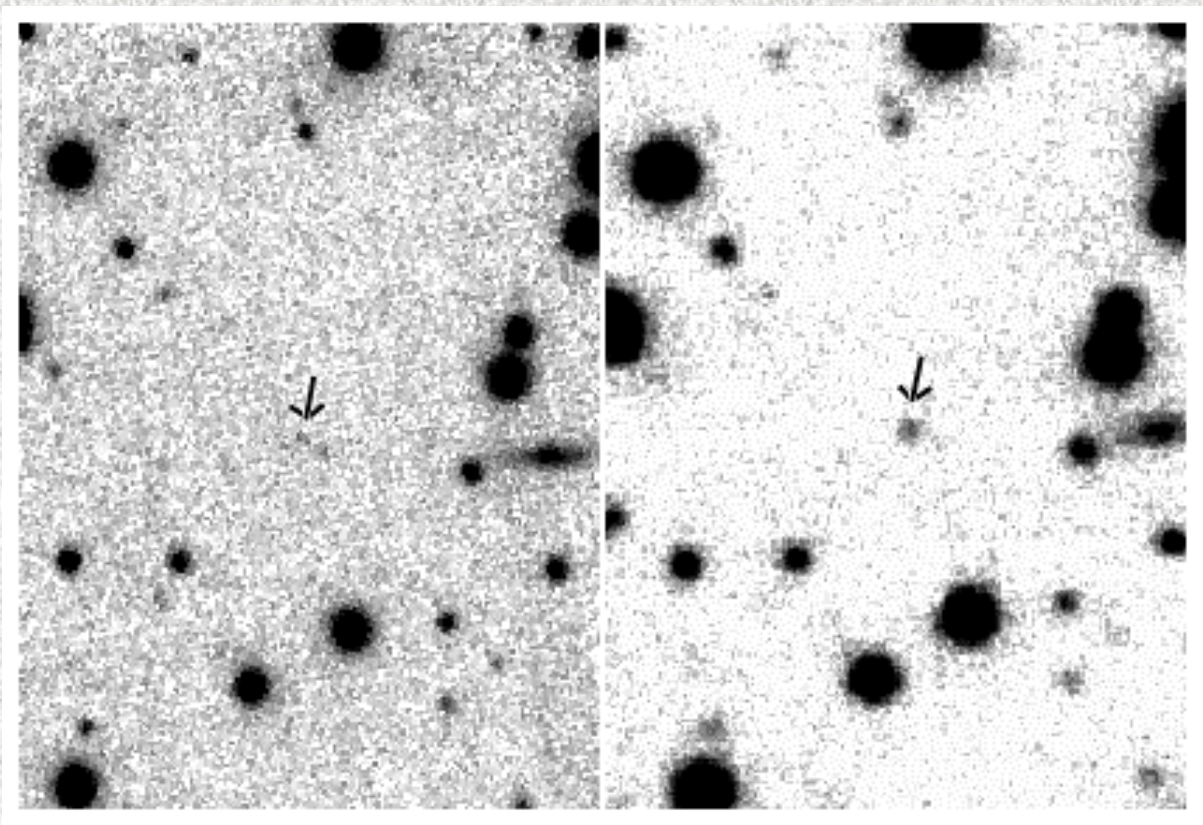
- Time of glitch consistent with burst epoch
- $\Delta\nu/\nu = 4.1 \times 10^{-6}$
- $\Delta\dot{\nu}/\dot{\nu} \sim 2.5$
- Torque returns rapidly toward the pre-outburst level in the weeks following



Kaspi et al. 2003

1E 2259+586 IR Flux Change

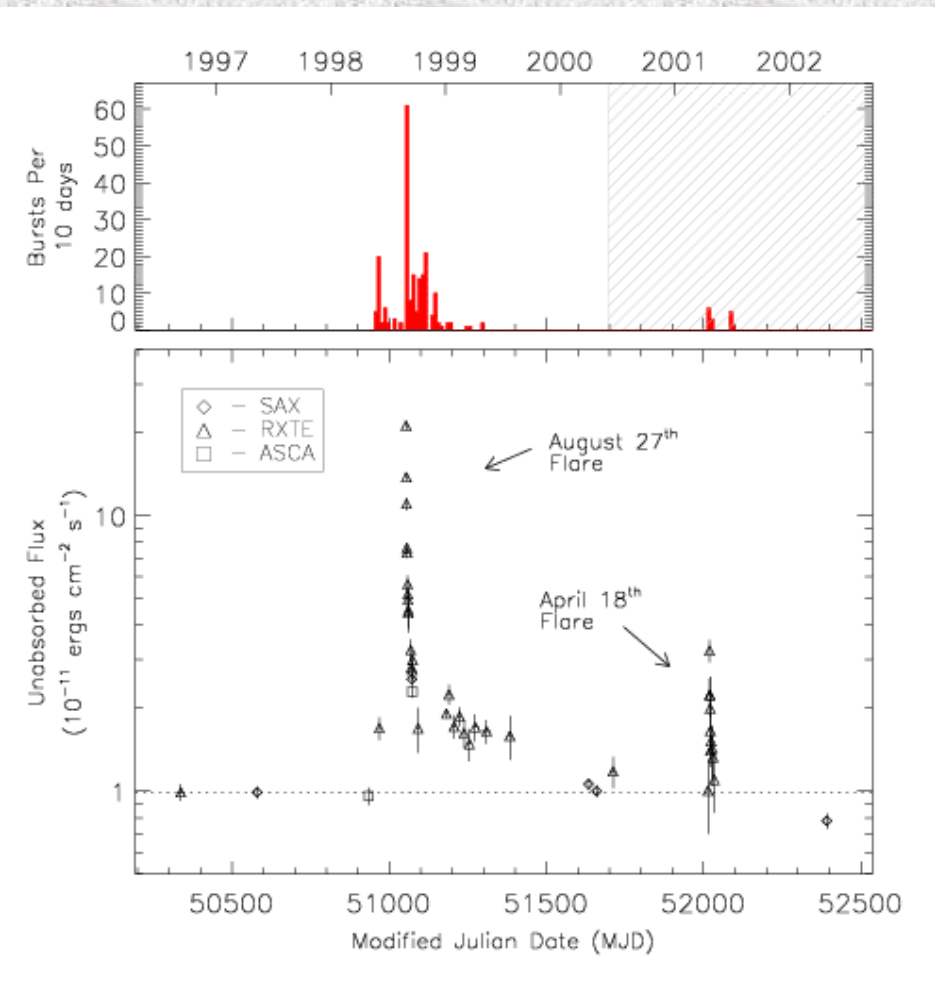
- IR flux (K_s band) increased by a factor 3.4
- IR flux excess decayed within 40 days following burst activity
  Israel et al. 2003



Kaspi et al. 2003

SGR 1900+14 Flux History

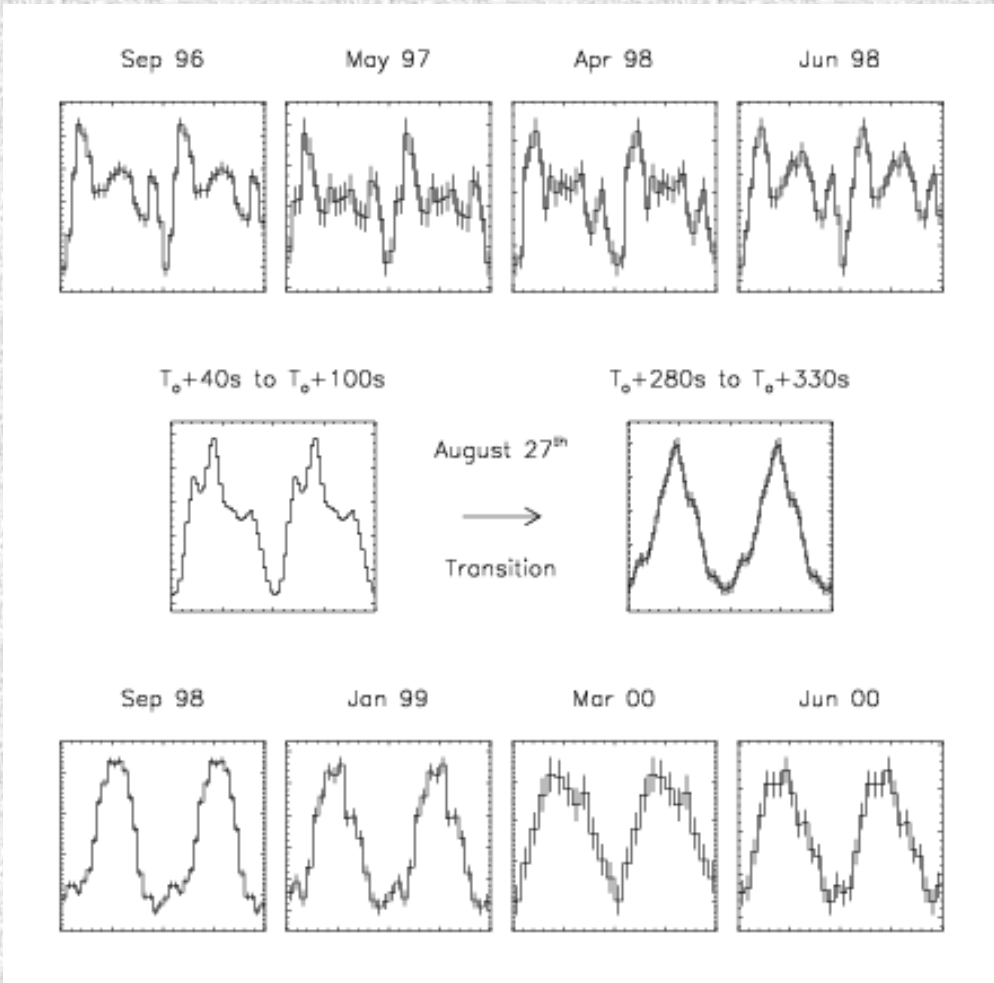
- Clear correlation with burst rate
- Two brightest flares stand out in persistent emission



Woods et al. 2001

SGR 1900+14 Pulse Profile

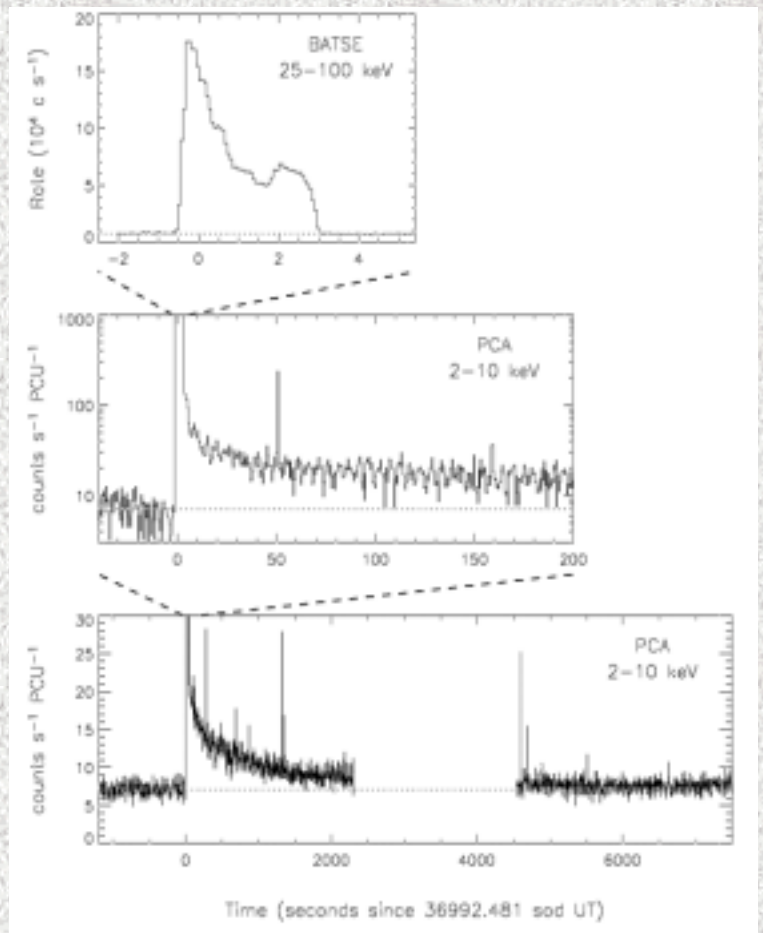
- Profile change seen in X-rays and γ-rays following giant flare of August 27, 1998
- Profile change is effectively permanent



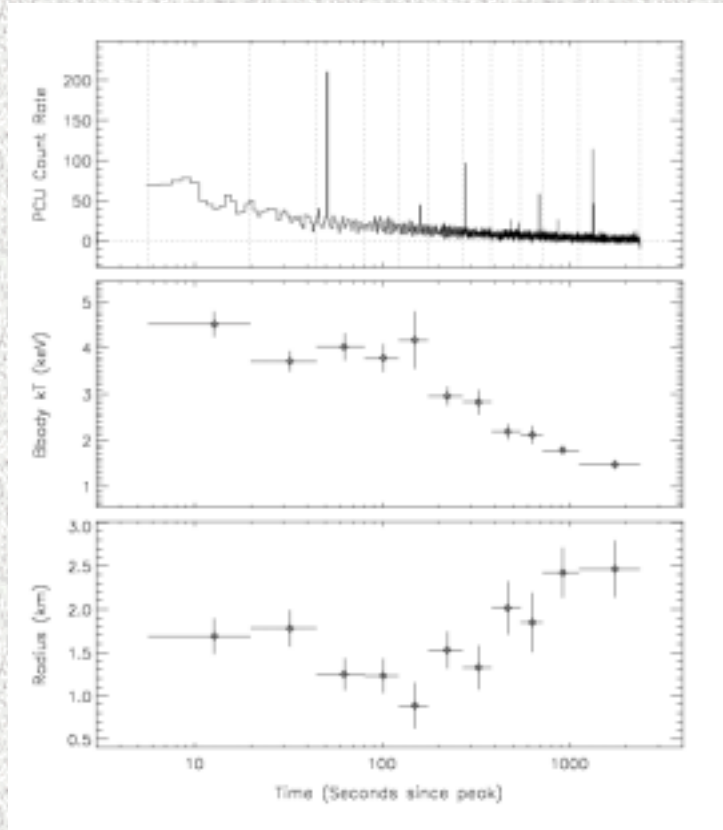
Woods et al. 2001

August 29 Tail Spectrum

SGR 1900+14



- Cooling blackbody emission during tail



Ibrahim et al. 2001
Lenters et al. 2002

Summary and Conclusions

- AXPs and SGRs are of the same nature
- Both AXPs and SGRs are most likely magnetars
- Any AXP can emit bursts, not just “intermediates”
- AXP/SGR outbursts are not uniform
- The major outbursts in these sources likely involve some sort of magnetic field reconfiguration

SGR Burst Activity